High efficiency diffractive optics for ToF and LiDAR applications

Niklas Hansson, Head of Application Engineering, NIL Technology
nh@nilt.com | www.nilt.com

EPIC Meeting on Diffractive Optics at Laser World of Photonics

Messe Munich, Munich, DE

28 April 2022, 2:00-4:00 PM

Me

NIL TECHNOLOGY

Niklas Hansson

- Head of Application Engineering
- Gothenburg, Sweden
- Joined NIL Technology 2012
- General focus across DOE, MOE and MLA to find best optical solution for a given product

Agenda

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1. NIL Technology
2. DOE applications – ToF/LiDAR
3. Conventional approach to ToF/LiDAR
4. NILT's approach to improving ToF/LiDAR by flat optics
5. Transmitter optics (Tx)
6. Receiver optics (Rx)
7. What is the difference between DOE and MOE
8. Volume Manufacturing
9. Summary

NIL Technology

NIL TECHNOLOGY

1. Manufacturing optical elements, components and modules

- Optical elements, **Rx and Tx:** diffusers, fanouts, collimators, focusing/imaging lenses; and building integrated functionalities
- Optical components and modules
- **Key technologies**: **DOE**, **MOE**, gratings, MLA…

2. Mastering technologies for diffractive waveguides

- **Masters (and working stamps)** for **VR/AR displays** to make diffractive planar waveguides

Copenhagen, Denmark (2006, HQ)
- Mastering
- Optics Design
- SCM
- Sales and Marketing
- Administration
- IPR

NILT, Copenhagen

East coast, US
- Mastering

West coast, US
- Sales

Zürich, Switzerland
- Engineering
- Prototyping and manufacturing lines
- Process and product development
- Project management

Gothenburg, Sweden
- Mastering
- R&D

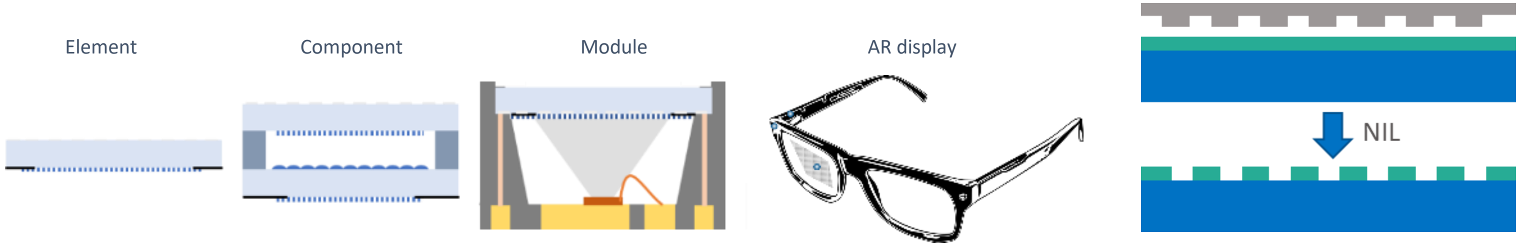
Other presence
- Ottawa, CA, sales
- Stockholm, SE, optics design

70+ employees
20+ nationalities
≈50% w PhD degree

Production
Six class 10-100 cleanrooms
Unique lithography machines
In-house etching + EBL Q4-22

IPR
>60 registered inventions

Key technologies



Investors

Joltcapital
ngp capital
VÆKSTFONDEN
European Innovation Council
Swisscanto Invest by Zürcher Kantonalbank

Niklas Hansson | NIL Technology ApS
Head of Application Engineering | nh@nilt.com

Technology | Illumination, Sensing, Imaging, Displays

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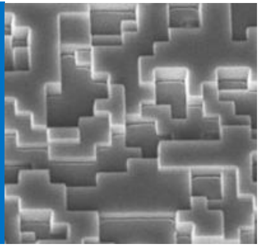
Diffractive Optical Elements (DOEs)



- → Smartphone, automotive, industrial, medical, etc.
- → Stacked and multi-element components
- → Combined flood/patterned light module, incl collimation, for NIR/SWIR applications

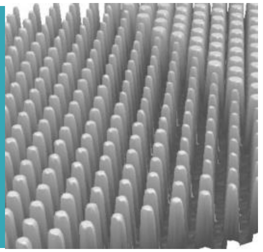
Diffuser
High efficiency, extremely low zero order
FOI >70° available, FOI >100° under development

Fan-out
Dot uniformity >90%. Efficiency: above 95% achieved
FOI >70° available, FOI >100° under development

Collimator
Collimation efficiency >80%. Diffraction limited spot size

Focusing Lens:
Focusing efficiency >80% Diffraction limited spot size

Meta Optical Elements (MOEs)



- → Smartphone , automotive, industrial, medical, etc.
- → Completely flat, thin imaging lenses: low F#, high RI, high FOV and concentricity in NIR & SWIR
- → Polarization control

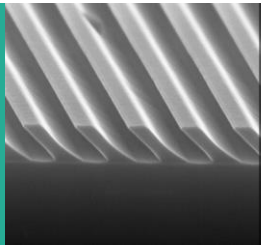
One Metasurface lens (1M) camera module
Efficiency >80%, FOV >100°, F# <1.2
Proto results available
Efficient in NIR & SWIR, up to 94% MOE lens demonstrated

Two Metasurface lens (2M)
Design and proto results available

Hybrid Lenses (1M3P, 2M2P,…)
Reduce Z-height of lens and system

Emitter optics
Diffusers and fan-out, high FOI, polarization control

Future Displays (AR/MR)



- → Input-, expander-, and output gratings for waveguides in AR/MR and auto HUDs
- → All grating types can be combined, in any relative placement and orientation

Slanted Gratings
Flat trench bottom. Tunable tapering
Roughness RMS <2 nm

Large Area Gratings
>12 cm^2, better than 0.1 nm pitch accuracy
11 nm global positioning accuracy
Non-periodic gratings are possible
Pixelated gratings are possible

Blazed/Binary Gratings
Down to 200 nm periods
Small anti-blaze
Roughness RMS <2 nm

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Head of Application Engineering | nh@nilt.com

Applications | DOE/MOE

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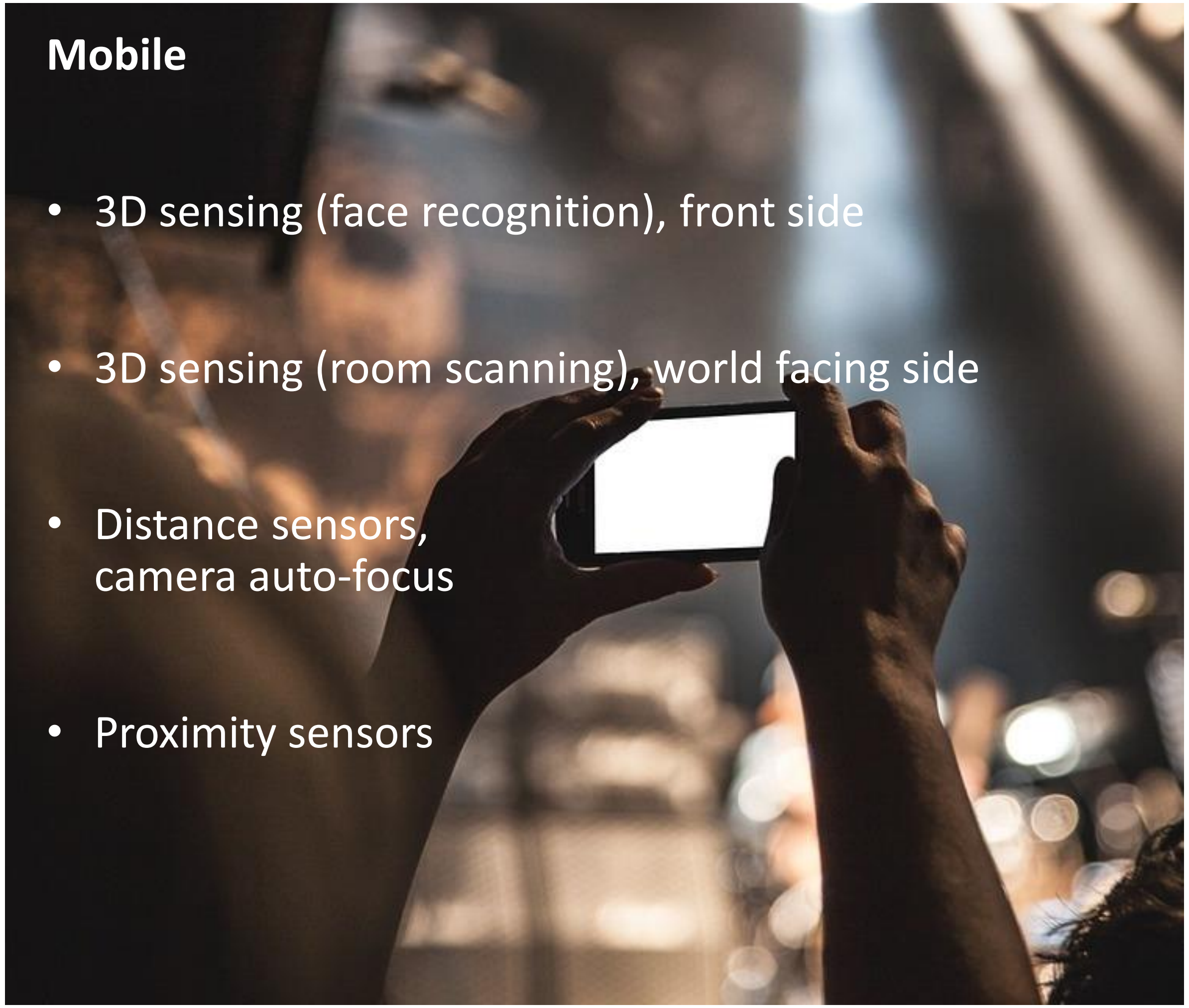

Mobile

- 3D sensing (face recognition), front side
- 3D sensing (room scanning), world facing side
- Distance sensors,
  camera auto-focus
- Proximity sensors

Automotive

- Lidar, long range
- Lidar, short range
- Driver monitoring

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Head of Application Engineering | nh@nilt.com

ToF/LiDAR | Conventional approach

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Receiver based on refractive optics

- Low relative illumination
- Sensitive to temperature
- Many lenses required
- Bulky (large TTL)

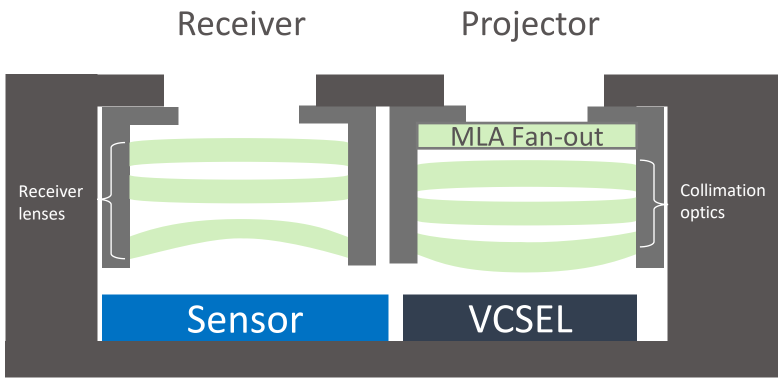

Fig 1. Sketch of Lidar.

Dot projection (MLA)

- Low dot uniformity

Flood illumination (MLA)

- Diffuse edge of FOV

NILT solution | Benefit from the power of diffractive optics today

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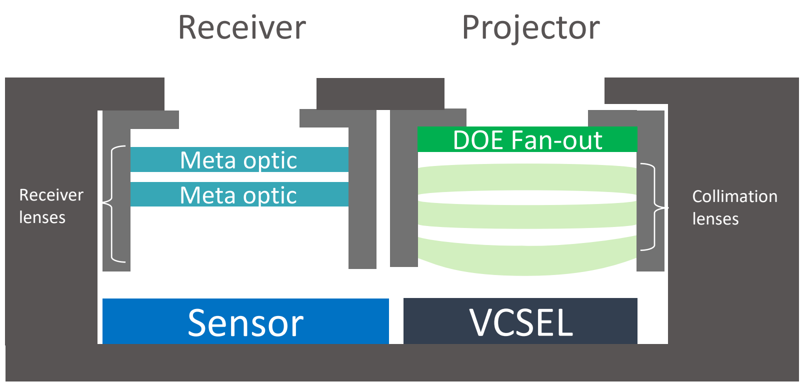
Flat lenses (MOE)

- High relative illumination
- Low sensitivity to temperture
- Reduced number of elements
- Lower TTL



Dot projection (DOE)

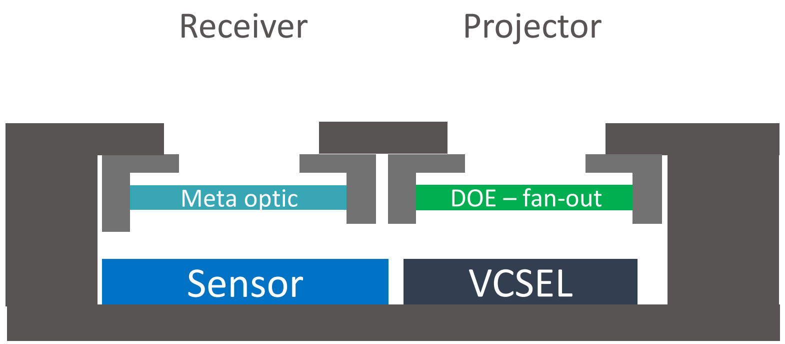
- Increased uniformity of dots
- High efficiency

1 MOE solution for NIR imaging available today

Ready solution – replace MLA with DOE fan-out and keep collimation solution for upgrading performance

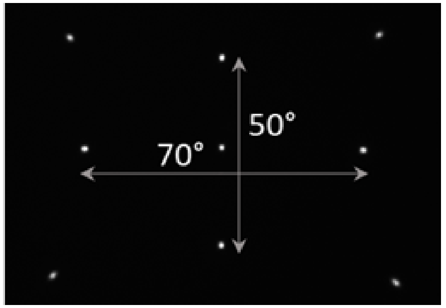
NILT solution | Next

Single element solutions with high efficiency for both Rx and Tx

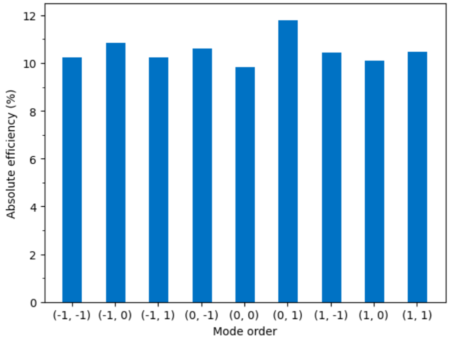


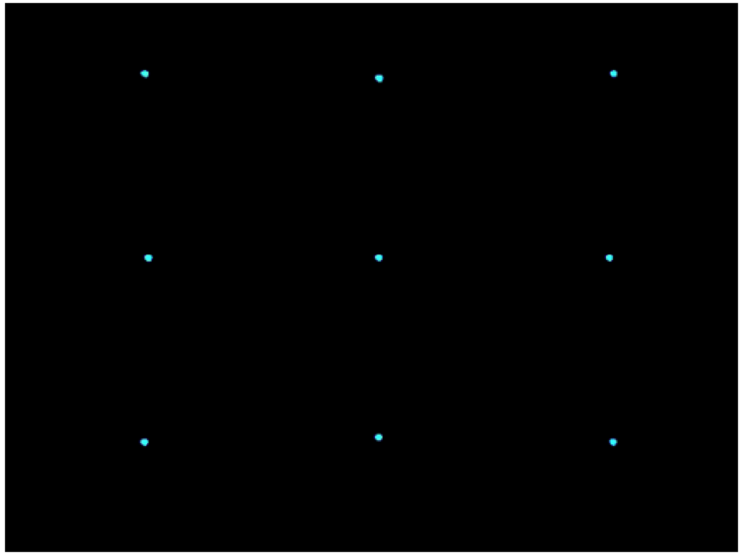
ToF/LiDAR | Tx – dot projection

- Polymer on glass
- Optimized for 940 nm VCSEL light source
- Absolute control of the zero-order transmission
- **High absolute efficiency, above 94%**
- **<10% non uniformity**

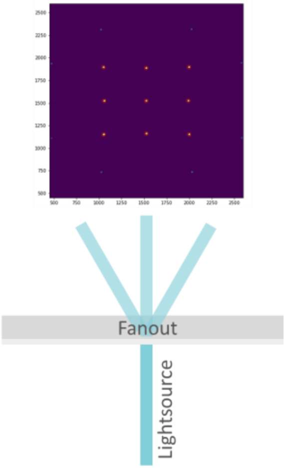


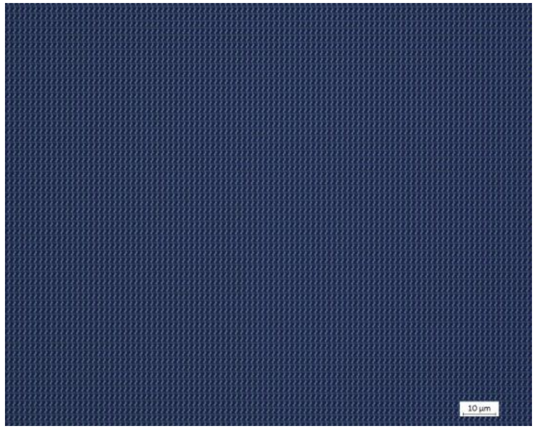
Projected on flat screen (measured)





Angular space





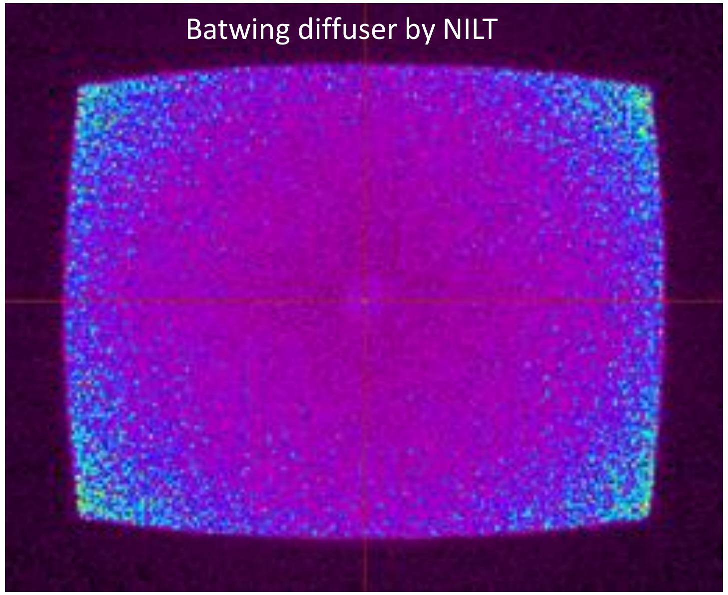
Parameter	Units	Specifications
Dot spacing	[°]	35x25
Number of dots		3x3
Target wavelength	[nm]	940
Absolute FOV efficiency @940nm	[%]	94.6
Non-uniformity error	[%]	9.1
Material		Polymer on glass with ARC coated backside
Active area	[mm^2]	2.5 x 2.5
Optimization condition		Optimized for unpolarized light at normal incidence

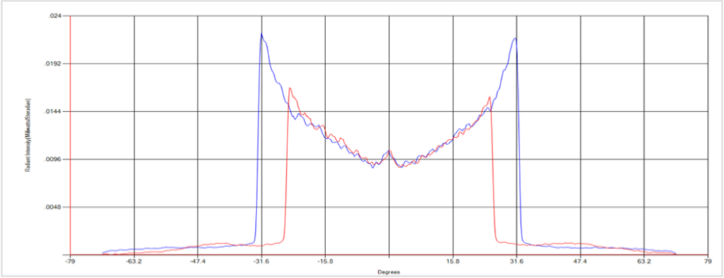
Niklas Hansson | NIL Technology ApS
Head of Application Engineering | nh@nilt.com

Flood illumination | DOE

NILT designs high performance diffusers:

- Tailored light profile to match receiver
- Wide FOI (>90°)
- Steep edges (90%➞10% in <1°)
- Low zero order (<0.1%)





Intensity profile measured with collimated input beam

Flood illumination with DOE vs MLA | Example: Diffuser for iToF

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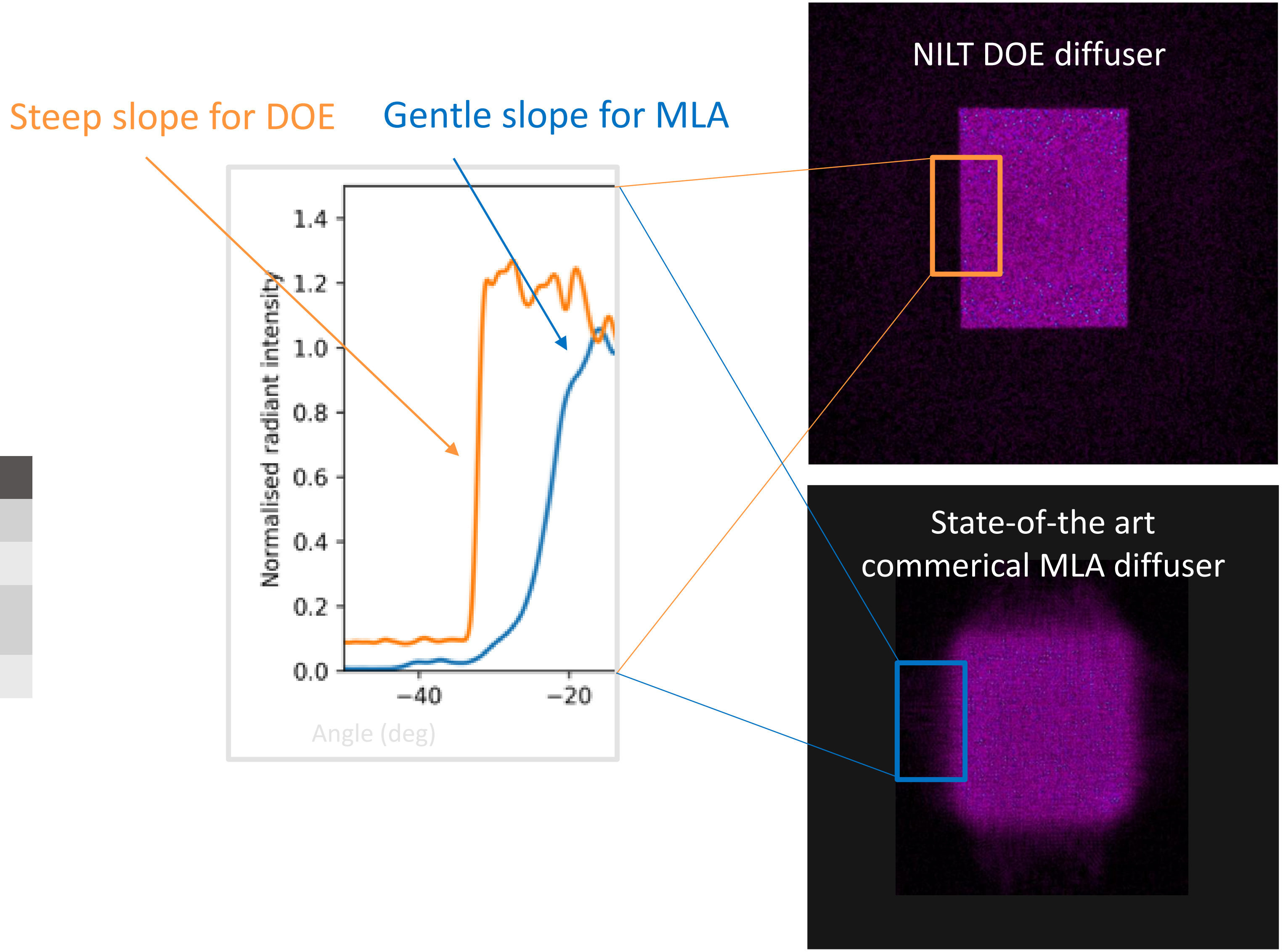
High control of illumination shape and corners compensate for diffraction efficiency losses. A higher FOI efficiency can be achieved compared to using MLAs

	DOE	MLA
Shape control	Good	Poor
Corners	Sharp	Washed-out
FOI	No loss outside FOI	High loss outside FOI
Efficiency in FOI	High	Low

DOE = Diffractive Optical Element
RI = Relative illumination
FOI = Field of Illumination
MLA = Micro Lens Array



Niklas Hansson | NIL Technology ApS
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Dual function elements | Diffuser & Fan-out

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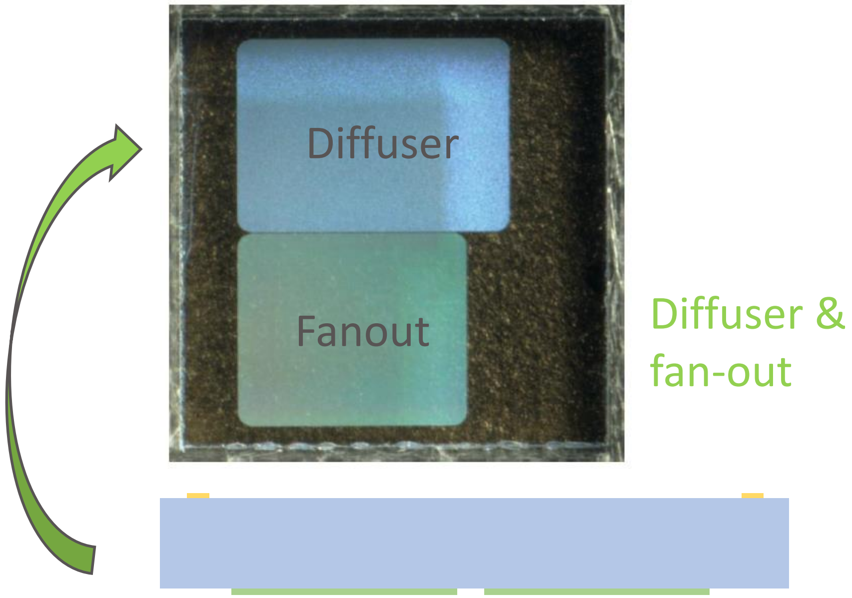
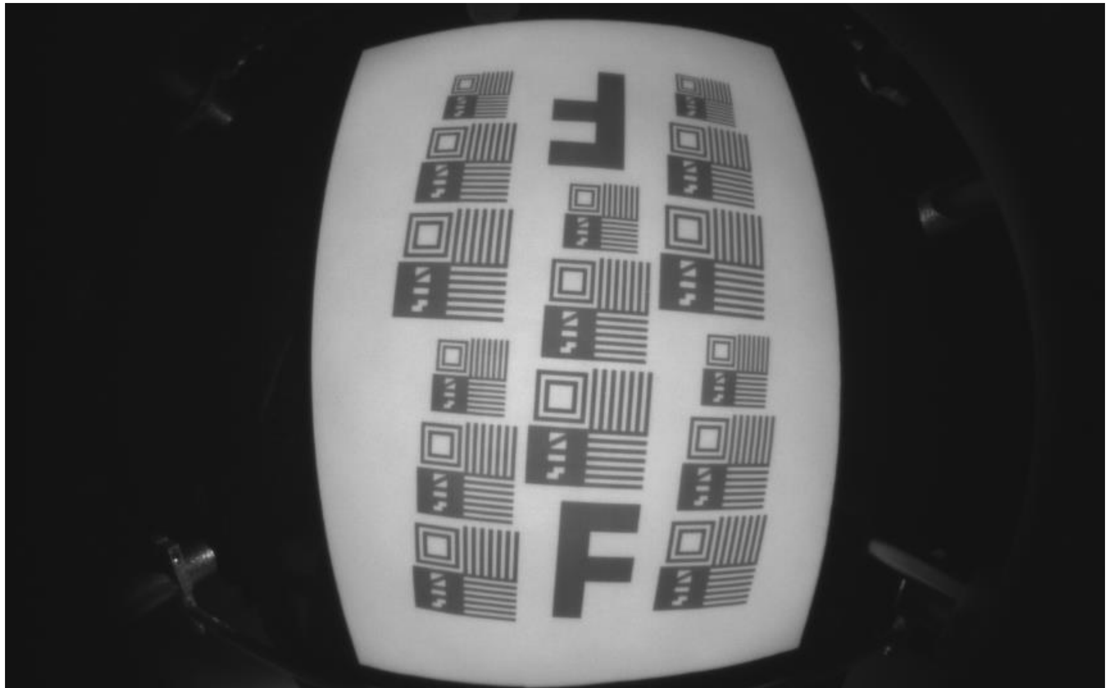
NILT's DOE technology platform enables manufacturing of different optical elements on the same optical die

- Example shown here integrates diffuser and fan-out on the same optical die
  - Multiple functionalities in one optical element
  - One element technology allows for more compact systems
  - One process step to make multiple functionalities
  - Simplified assembly
- Many other combinations possible



Receiver | Single surface meta camera (1M @ 940 nm)

In-house designed & manufactured 1M samples



1M camera module live demo @ Booth 525, Hall B6

Parameter	Specifications
Wavelength	940 nm
EFL	1.24 mm
TTL	3.1
FOV, diagonal	80°
F/#	1.6
CRA	<1.5°
Distortion	23%
Aperture Diameter	0.78 mm
Lens Diameter	Ø 2.50 mm
BFL	1.213 mm

Lens MTF (Average Sag/Tan)
Nyquist = 227 lp/mm
0.0 F = 0.75
0.5 F = 0.74
0.8 F = 0.71

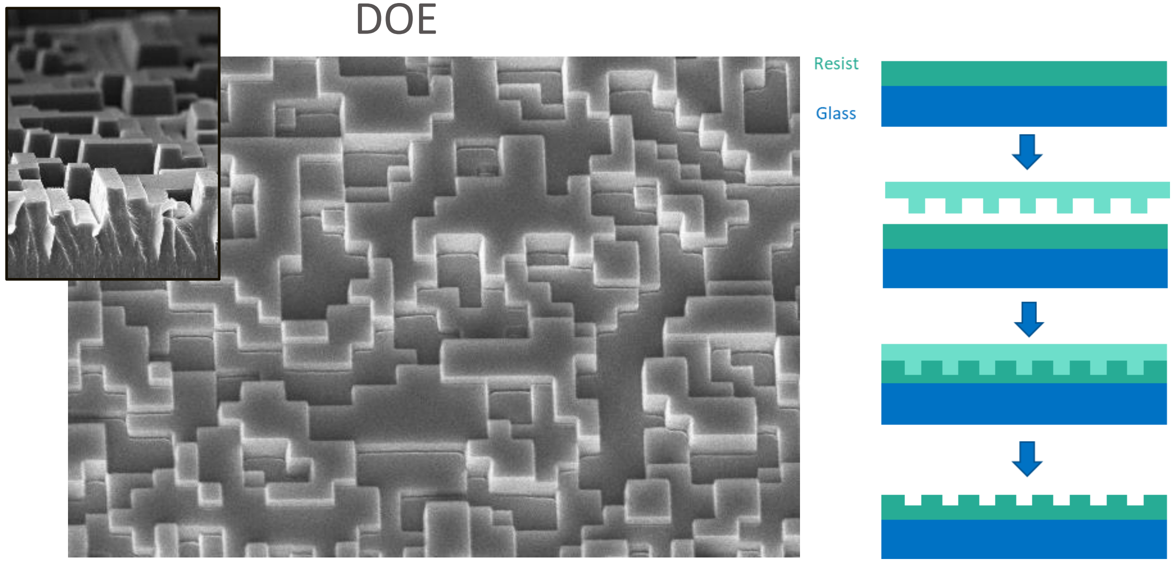
1M = High performance with only 1 optical surface

- 90% efficiency
- Telecentric, high RI design
- Good performance match between realized prototype and design
- Designed, prototyped and characterized inhouse
- Samples available

Niklas Hansson | NIL Technology ApS
Head of Application Engineering | nh@nilt.com

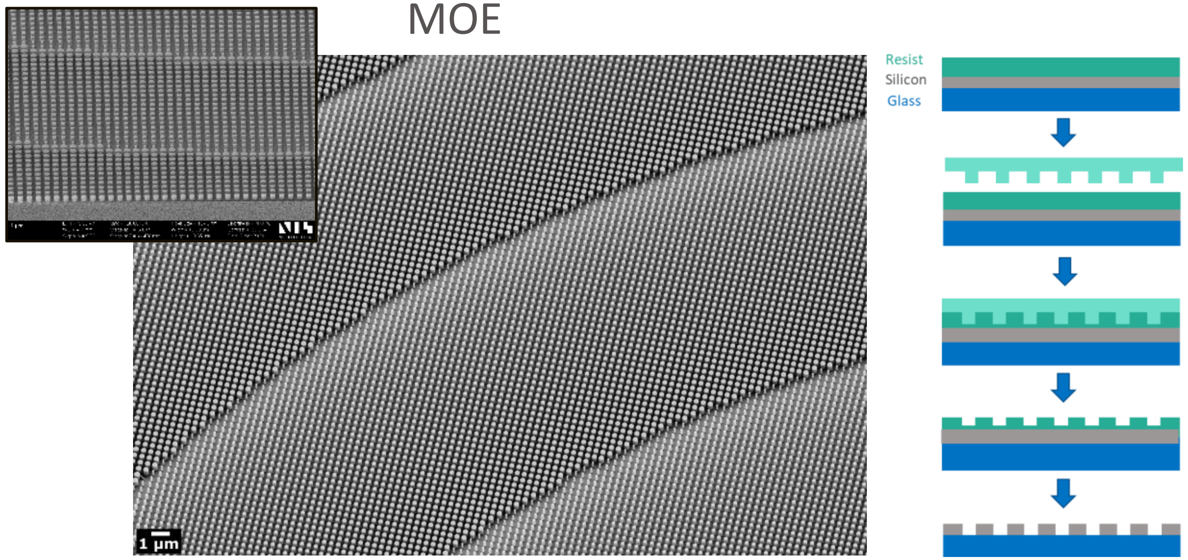
DOE and MOE

DOE



- Light is considered as waves and controlled by phase shifts
- Characteristic length scale ≈λ
- Polymer on glass
- DIFFRACTIVE

MOE

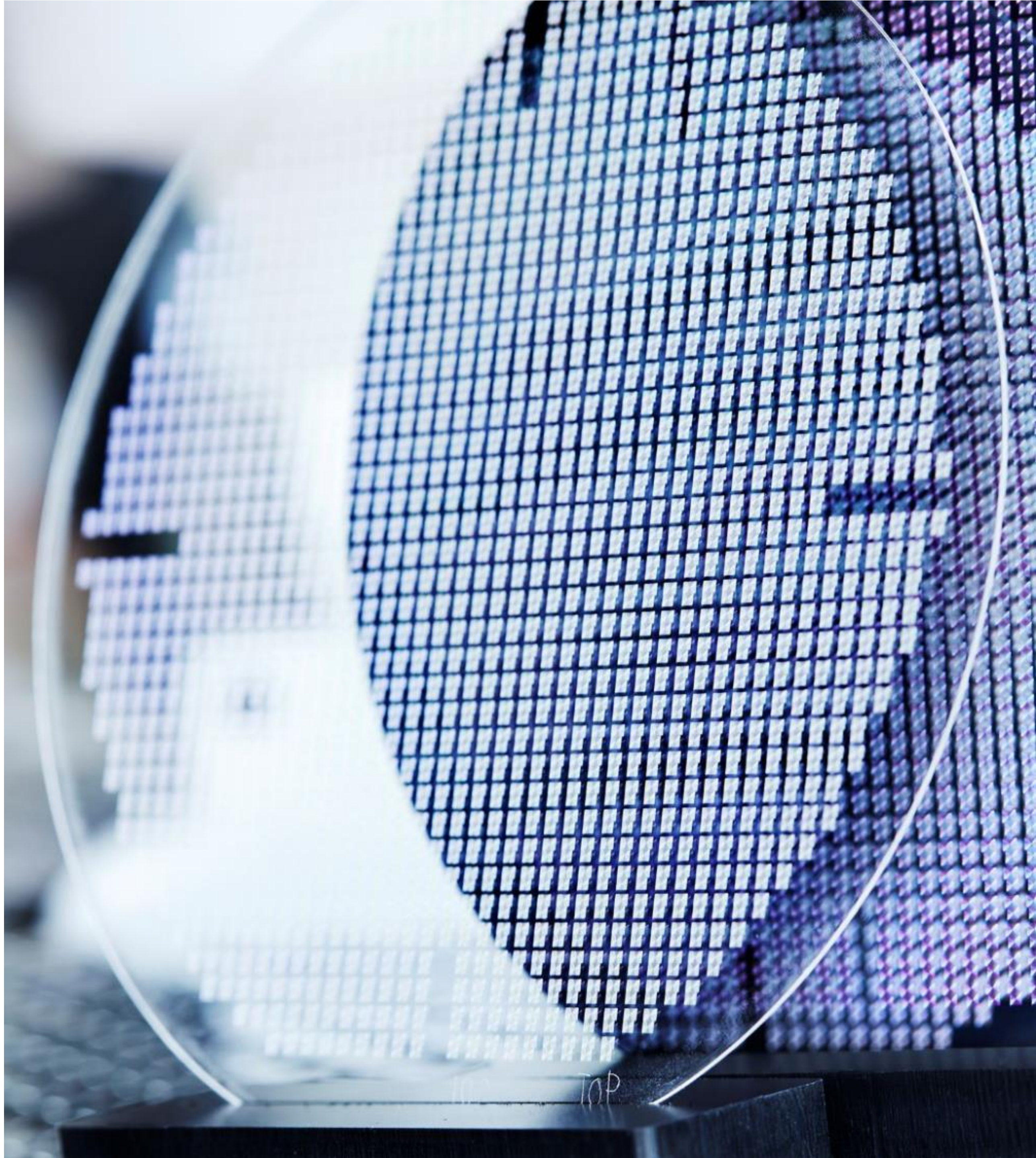


- Light controlled by meta-atom resonance frequencies
- Characteristic length scale <<λ
- High refractive index material on glass (e.g., Si on glass for NIR, TiO2 for vis)
- DIFFRACTIVE

Ready for Mass Production

Design, prototyping and testing of optical elements entirely within NILT → fast development cycles

- Mass Production by NIL
    - Replication and nanoimprint lithography
    - Proven process
    - In-house assembly of optical components by wafer level stacking is possible
- Wafer level production process enables cost effective mass production
- 100% Functional Optical testing on wafer
- NILT Standard Reliability Stress Conditions
    - Reflow
    - Temperature Cycling
    - High humidity high temperature cycling



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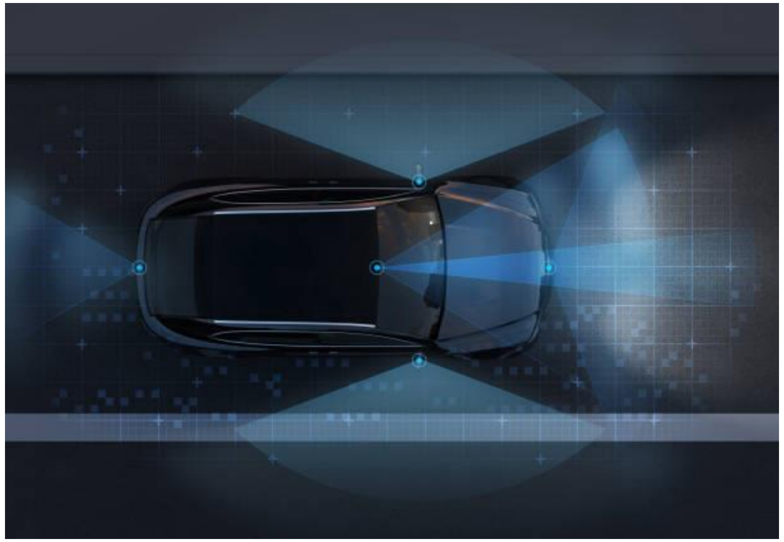
Summary | ToF/LiDAR application benefits

Rx - Receiver

- Fewer elements
- More compact system (reduced TTL)
- Increased light collection
- Higher relative illumination

Tx - Projection

- More light through the system by pushing efficiency
- Higher uniformity across FOV



This enables higher accuracy, lower power consumption and longer range

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nilt.com

P +46 708 57 96 69

M nh@nilt.com

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